PREDICTING PHENOLOGY USING TIME SERIES REMOTE SENSING DATA: INITIAL RESULTS FOR THE INDIAN FORESTS

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Abstract— Time series (2003 to 2007) MERIS Terrestrial Chlorophyll Index (MTCI) products were used to predict the phenology of different forest types in India. The MTCI data were corrected for noise using a temporal moving window filter and then a Fourierbased smoothing was applied without compromising annual phenological cycle. Finally, the phenological variables i.e. onset of greenness and end of senescence, were predicted through iterative search for each pixel using 1.5 years of Fourier smoothed data. Different forest types were extracted from a global land cover map (GLC 2000) and corresponding phenological variables were clipped. Finally, for each forest type, median of phenological variables was derived from four year results and then a spatial majority filter was applied to the 1◦ x 1◦ tiles covering complete India. This study presents the initial results derived for the evergreen, semi-evergreen, moist deciduous and dry deciduous forest in India.

1 INTRODUCTION

Quantitative phenological variable is vital for regional and global research into biophysical as well as ecological phenomena such as net primary productivity, the seasonal CO2 cycle, climate change and vegetation mapping (Botta *et al.* 2000; Chen *et al.* 2001, Nemani *et al.* 2003; Roy *et al.* 2006). Remote sensing technology has provided an impetus to phenology studies, and in the past two decades many studies have predicted the seasonal phenological pattern of crops and natural vegetation over vast area (Goward *et al.* 1985; Justice *et al.* 1985; Malingreau, 1986; Townshend *et al.* 1987; Lloyd, 1990; Myneni *et al.* 1997; Botta, 2000; Zhang, 2003; Piao *et al.* 2006;). Most satellite sensor-derived phenology studies have relied on the normalised difference vegetation index (NDVI) estimated from various sensors including the Advanced Very High Resolution Radiometer (AVHRR) and Moderate Resolution Imaging Spectroradiometer (MODIS) (Reed *et al.* 1994; Myneni *et al.* 1997; Zhou *et al.* 2001; White *et al.* 2005). However, due to the limitations of the NDVI, such as saturation at high levels of vegetation biomass and chlorophyll concentration (Gitelson and Kaufman, 1998; Huete *et al.* 2002; Mutanga and Skidmore, 2004) extracting reliable phonological variable is difficult. In this regard, the current study attempted to extract phenology from remote sensing derived chlorophyll index. MERIS Terrestrial Chlorophyll Index (MTCI) level-3 prodcuts (Dash and Curran, 2004) were utilised for this purpose. MTCI is calculated as the ratio of the difference in reflectance between wavebands 10 (753.75 nm) and 9 (708.75 nm) and the difference in reflectance between wavebands 9 and 8 (681.25 nm) of the MERIS standard band setting. MTCI has limited sensitivity to atmospheric effects and also to soil background and view angle (Dash and Curran, 2007). Its availability as near real-time weekly and global MTCI composites (Curran *et al.* 2007) enables researchers to estimate phenological variables accurately. Hence, this research aims to utilize MTCI 8-day composite temporal data to extract phonological variables over India. Remote sensing-based studies of phenology are less common in India (Panigrahy *et al.* 2005; Joshi, 2006; Singh *et al.* 2006; Prasad *et al.* 2007; Upadhyaya *et al.* 2008) and many of them were focused on crop phenology. There is a pressing need to establish a phenological network in India (Moza and Bhatnagar, 2005; Kushwaha and Singh, 2008). Therefore, the present study aims to map the variation in phenological variables for several natural vegetation types in India.

2. STUDY AREA

The Indian sub-continent is very diverse in climate, altitude and physiography. It is enriched with many vegetation and biodiversity zones spreading over Central India, the Eastern and Western Ghats in the south, Eastern Himalayas in the north-east and Western Himalayas in the north of the country. Of the total geographical area (≈ 328 million ha) of the country, 67.71 million ha (20.60%) constitutes forest cover (SFR, 2005). Variation in the duration of sunlight, precipitation and temperature are critical for plant survival and reproduction (Corlett and Lafrankie, 1998; Sarmiento, *et al.* 1998; Moza and Bhatnagar, 2005). Hence, to understand the response of vegetation with climatic variables, and to predict future climate change and related vegetation dynamics, it is imperative to develop a scientific database on spatio-temporal variation in phenological events in India which, at present, does not exist at the national level (Moza and Bhatnagar, 2005; Kushwaha and Singh, 2008).

3. METHODOLOGY

The study utilised a temporal (8-day) composite of MERIS MTCI data (level-3 product) for the period 2003 to 2007, and a Global Land Cover map (GLC2000). MTCI data were downloaded from the Natural Environment Research Council (NERC) Earth Observation Data Centre (NEODC) website (http://www.neodc.rl.ac.uk/). The GLC2000 was downloaded from the GLC global database website (http://wwwtem.jrc.it/glc2000/). The study area was extracted from the input data set. There are a total of 46 bands in the MTCI level-3 product, where each band represents approximately 8 days. **Table 1** provides the MTCI Composite Number, representing each band, and its corresponding week in a year. The time series MTCI data were cleaned first, a smoothing operation was applied using Discrete Fourier transform (Jakubauskas *et al.* 2001; Wagenseil and Samimi, 2006) (without affecting the natural phenological cycle) and, finally, the phenological variables (i.e. onset of greenness-OG and end of senescence-ES) were extracted. Onset of greenness refers to the starting point of greening, and end of senescence refers to the end of leaf fall. A software toolset was developed in ArcGIS using Visual Basic and Arcobjects, and utilised for the study.

Table 1: The MTCI composite number and its respective week

Comp. No.	Dates	Comp. No.	Dates	Comp. No.	Dates
1	01-08 Jan	***17***	09-16 May	***33***	14-21 Sep
2	09-16 Jan	***18***	17-24 May	***34***	22-29 Sep
3	17-24 Jan	***19***	25 May - 01 Jun	***35***	30 Sep -07 Oct
4	25 Jan-01 Feb	***20***	02-09 Jun	***36***	08-15 Oct
5	02-09 Feb	***21***	10-17 Jun	***37***	16-23 Oct
6	10-17 Feb	***22***	18-25 Jun	***38***	24-31 Oct
7	18-25 Feb	***23***	26 Jun – 03 Jul	***39***	01-08 Nov
8	26 Feb - 05 March	***24***	04-11 Jul	***40***	09-16 Nov
9	06-13 Mar	***25***	12-19 Jul	***41***	17-24 Nov
10	14-21 Mar	***26***	20-27 Jul	***42***	25 Nov – 02 Dec
11	22-29 Mar	***27***	28 Jul - 04 Aug	***43***	03-10 Dec
12	30 Mar - 06 Apr	***28***	05-12 Aug	***44***	11-18 Dec
13	07-14 Apr	***29***	13-21 Aug	***45***	19-26 Dec
14	15-22 Apr	***30***	21-28 Aug	***46***	27-31 Dec
15	23-30 Apr	***31***	29Aug – 05 Sep		
16	01-08 May	***32***	06-13 Sep		

4. RESULTS AND DISCUSSION

Figure 1 shows the annual variation in MTCI data and its respective Fourier smoothed data, for the location 95◦ 31’ 13” E, 27◦ 15’ 51” N, for the years 2003 to 2007. For some forest types the phenology growth curve extends more than one year data. Hence, the study considered 1.5 years data such as to extract both the OG and ES for every pixel. The MTCI composite number was used to represent the date of the resultant phenological variables (user should refer to **Table 1** for date interpretation).

4.1 Spatial Phenology Maps

The study extracted four spatial maps of phenology by considering 1.5 years data; one each for 2003-2004, 2004-2005, 2005-2006 & 2006-2007. The estimated phenological variables need to be segregated for each natural vegetation type available in the GLC2000. For this purpose, the spatial resolution of GLC2000 was converted from 1 km to that of the MTCI (0.041592◦ ≈ 4.6 km) utilizing a spatial majority-based categorical aggregation (He *et al.* 2000). Masks were prepared for the required vegetation types from the aggregated GLC2000 and used to extract the phenological variables. In this study, the phenological variables were presented as a representative majority within a 1◦ x 1◦ tile of grids overlaid over the study area to facilitate ground validation. The higher values of composite number for end of senescence should be interpreted as a continuation in the next year (e.g. a value of 60 for the End of Senescence represents the value 14 [i.e. 60 – 46] in the next year). The grid cells falling outside India are not shown, and only the inner portion was retained for the grid cells falling at the boundary.

4.1.1 Tropical and sub-tropical evergreen forest

For the evergreen vegetation type, the MTCI value was consistently high throughout the year. MTCI values of tropical evergreen were higher than sub-tropical evergreen, but the variation in the MTCI values was greater for the later. **Figures 2(*a*) & 2(*b*)** depict samples of the actual variation found in MTCI for tropical evergreen and sub-tropical evergreen forest, respectively. The sample points were selected over the middle portion of related vegetation patches in the GLC2000 classified image which was further confirmed through other studies (Ralhan *et al.* 1985; Bhat, 1992; Behera *et al.* 2001). The samples of tropical evergreen forest were located in Karnataka, in Kerala and in Meghalaya. For sub-tropical evergreen forest the samples were in Meghalaya, in Arunachal Pradesh and in Uttarakhand.

Tropical evergreen forest was found in the Western Ghats in Karnataka, Kerala and the bordering region in Tamil Nadu; in the south-eastern part of Meghalaya and nearby southern region in Assam, Nagaland and south & eastern parts of Arunachal Pradesh; in Andaman & Nicobar Islands and; few scattered patches in Orissa. The sub-tropical evergreen forests were found in Uttarakhand, Meghalaya, Assam, Aurnachal Pradesh, Manipur and Nagaland.

Fig. 3(*a*) & 3(*b*) depict the OG and ES respectively within each grid cell for tropical evergreen forest. The OG occurs earlier (late February and early March) in the southern part of India than in the northern part (late March). The OG, more or less, follows a similar pattern (late March to early April) in the north-east. The OG in Kerala seems to follow a unique early occurrence pattern relative to other parts of the country. **Fig. 3(*c*) & 3(*d*)** depict the OG and ES respectively for sub-tropical evergreen forest. The OG occurred almost at the same time during April for Uttarakhand and north-eastern states, but ES arrived early in December for Uttarakhand forest whereas it occured in February-March for north-eastern states.

4.1.2 Tropical semi-evergreen forest

Figure 2(*e*) illustrates variation in the MTCI for tropical semi-evergreen forest. The samples were taken from Kerala, Arunachal Pradesh and Goa. In a semi-evergreen forest, the lower layer of a tree retains its foliage while the upper layer is defoliated for some period and hence the variation in MTCI value was high for this forest compared to evergreen forest. The variation in MTCI values differs between regions. Goa had smaller values of MTCI compared to Kerala and Arunachal Pradesh. The southern region of the Western Ghats exhibited an early OG in February compared to other regions where the OG was in March-April.

Figures 4(*a*) & 4(*b*) reveal the OG and ES derived for semi-evergreen forest. The start date of OG in the Western Ghats varied from January to April and, in Orissa and the north-eastern region it varied from March to April. The end date of the ES varied from February to April. The forests in Arunachal Pradesh exhibited a late start of OG and late ES.

4.1.3 Tropical moist and dry deciduous forest

Figures 2(*c*) & 2(*d*) depict the actual variation found in MTCI for tropical moist and dry deciduous forest, respectively. For the deciduous vegetation type, the variation in MTCI values was very clear in comparison to evergreen forest. The Moist deciduous forest had a clear cyclic pattern with a faster rate of greening than dry-deciduous forest. The difference in MTCI values between peak and minimum value was greater for moist-deciduous than dry-deciduous forest. A prolonged leafless period during cool winter months was reflected through consistent low values of MTCI for the dry deciduous forest. However, for moist-deciduous forest leaf fall and greening occurred continuously. The samples for moist deciduous forest were taken from Orissa, Uttarakhand, Karnataka and Madhya Pradesh, and for dry-deciduous forest the samples were from Orissa, Madhya

Pradesh and Jharkhand.

The moist-deciduous forest in Uttarakhand exhibited larger values of MTCI and a distinct growth pattern compared to all other places. The amplitude and rate of fluctuation of MTCI values of the moist deciduous forest in Karnataka was less than for other locations. In Orissa, the forest seemed to retain the leaves for longer due to fewer cooler months, which was reflected through the increased width of the phenology peak. Dry-deciduous forests exhibited variation in the OG at different locations. However, they all had a similar increased leafing activity in the rainy season during July to September. Orissa and Madhya Pradesh exhibited lower values of MTCI during the peak growing season which may be attributed to lower moisture availability in those regions.

Figures 5(*a*) & 5(*b*) show the OG and ES respectively, estimated for the moistdeciduous forest. A clear pattern of early start of OG was found in the southern and eastern regions while a late start was revealed in the northern region. **Figures 5(*c*) & 5(*d*)** reveals the OG and ES, respectively, for the dry-deciduous forest. The length of growing season (i.e. difference between ES and OG) is shorter for dry-deciduous than moist-deciduous forest. The dry regions had a late start of OG and early finish of ES, which is reflected as a red and blue interchanging pattern in the resultant images.

4.2. Checking the results with existing literatures

A limited number of existing publications were utilised to validate the results of the current study, and the results matched in majority of the cases. The observations made from other studies are presented herewith for comparison. Boojh and Ramakrishnan (1983) studied deciduous tree species near Shillong in Meghalaya and reported leaf flushing during early March to early April. Shukla and Ramakrishnan (1984) studied tropical trees in the reserve forest at Lailad, Meghalaya and reported peak leaf fall during the dry period of March-early April and leaf production during April-May and in July-August. Ralhan *et al.* (1985) observed tree layer in Kumaun Himalayan forests and reported leaf drop activity immediately followed by leaf flushing during March-April for evergreen species, and for deciduous species leaf drop was during November-February. Prasad and Hegde (1986) studied Bandipur tropical rain forest in Karnataka and reported first peak of leaf emergence in April-May. Newton (1988) studied moist deciduous forest in the Kanha Tiger Reserve in Madhya Pradesh and reported peak leaf shedding during February-April, and flushing during May-June. Bhat (1992) studied tropical moist forests in the Western Ghats region in the Uttara Kannada district of Karnataka and reported peak leaf emergence during February-March, and abscission of leaves lasting up to January. Murali and Sukumar (1994) revealed a leaf flushing during March-May in the tropical dry forest (deciduous and thorn) in Mudumalai Wildlife Sanctuary, Tamil Nadu. Kikim and Yadava (2001) studied the phenology of tree species in the subtropical forests of Manipur and reported leaf flushing at the beginning of the warm dry period (i.e. March-April) and leaf fall in the cool dry period during January-February. Sundarapandian *et al.* (2005) reported peak leaf emergence during February-March for the moist deciduous trees at

Kodayar, Tamil Nadu. Singh and Kushwaha (2005) studied the phenology of forests in the Hathinala forest (tropical deciduous) in Sonbhadra district of Uttar Pradesh and reported leaf flushing during March-June. Mishra *et al.* (2006) reported a peak leaf drop in March and leaf flushing during April for the moist deciduous forests in Similipal Biosphere Reserve in Mayurbhanj district of Orissa.

Joshi *et al.* (2006) mapped the vegetation types of India and reflected coarse phenological variables using NDVI from Indian Remote Sensing Satellite's Wide Field Sensor (IRS-WiFS) for vegetation types in India. However, their study did not reveal phenology for full India as it did not aim to estimate phenological variables. Prasad *et al.* (2007) extracted phenological variables by thresholding AVHRR NDVI values. However, they did not reveal the phenological variables for all of India, but for only eight sample sites. Their study mainly focused on analysing NDVI variation with temperature and rainfall.

4.3 Reliability analysis

The phenological variables derived for four annual periods (2003-04, 2004-05, 2005-06 & 2006-07) were not exactly the same and hence the Kruskal-Wallis test was used to determine if there was a significant difference between the phenology of the four years. It was observed that for OG ($p=0.016$) and length of season ($p=0.018$) the difference among years was marginally significant and for ES ($p=0.23$) the difference between years was insignificant.

5. CONCLUSION

The current study attempted to estimate the spatial pattern of phenology for natural vegetation in India. The current study used MERIS-MTCI product for the years 2003 to 2007. The results were checked with existing reports and research papers. Future research would attempt to increase the accuracy of the resultant maps and further strengthen the field components.

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